AN ANALYSIS OF THE SENSITIVITY TO CONTAMINATION OF THE SANTA CLARA VALLEY GROUNDWATER AQUIFERS BASED ON THE USEPA DRASTIC METHODOLOGY

December 1999

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Roger Pierno
Assistant Engineer II
Water Resources Management

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By

Roger Pierno
Assistant Engineer II
Water Quality Unit
Water Resources Management Group

With major technical contributions from:

Randy Behrens
Water Quality Specialist II
Water Quality Unit

and

Kelly Parton
Water Quality Specialist I
Water Quality Unit

Administrative oversight was provided by:

Tracy Hemmeter
Senior Water Quality Specialist
Water Quality Unit

Santa Clara Valley Water District, San Jose, California

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ABSTRACT

Approximately half the water used in Santa Clara County (County) is groundwater. Many areas in the groundwater basin are assumed to be highly sensitive to contamination, but a basinwide, comprehensive quantitative comparison of the relative sensitivities of these distinct groundwater areas has not previously been performed. The inconsistent level of knowledge of groundwater sensitivity throughout the County probably leaves large sensitive portions of the basins with little or no oversight or protective measures. Using a geographic information system (GIS), the United States Environmental Protection Agency's (USEPA) DRASTIC methodology was employed to develop a numerically-based map of the sensitivity of areas in the County's groundwater basins to contamination. This map is an amalgam of the seven principal parameters that affect water and contaminant movement to and within aquifers. It, therefore, can represent the potential for pollution movement from the surface to potable groundwater. The seven parameters are Depth to water (dtw), net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity of the aquifer. These seven factors form the acronym DRASTIC.

The DRASTIC map created by this project provides information on the sensitivity of the groundwater to contamination originating at the ground surface. This map covers each of the groundwater subbasins at a resolution of approximately 50 acres. By using a GIS to layer a reference map over the DRASTIC map, a location of interest can be identified and the relative pollution sensitivity of that area in the groundwater basin can be instantly determined. In using this map, one must keep in mind that it represents relative sensitivity, it does not indicate the absolute sensitivity of any area. To validate the DRASTIC map and determine its real world usefulness, areas in the map were compared with several areas of known sensitivity. This comparison shows that the map appears to represent basin sensitivities accurately and should, therefore, be useful in depicting areas of high sensitivity. The map thereby highlights areas where groundwater protection efforts are needed and will help Santa Clara Valley Water District (District) staff focus on those areas. It will also be useful to planners when they review development proposals. As an additional benefit of this project, many individual GIS data layers were obtained or created that are useful in and of themselves.

INTRODUCTION

About half the water used in Santa Clara County comes from groundwater. All of the water used in southern Santa Clara County is derived from groundwater. These groundwaters are pumped primarily from alluvial confined and unconfined aquifers. Both types of aquifers, but especially the unconfined aquifers, are sensitive to contamination from activities on the land surface. Unconfined aquifers have little natural protection from surface contamination since a significant aquitard (low permeability zone) is not present above them. The confined aquifers are sensitive to contamination due mainly to the presence of poorly constructed wells and abandoned wells. The poorly constructed wells, those with inadequate seals or with perforations above and below the major aquitard, and abandoned wells act as conduits capable of carrying contamination past the aquitard to the drinking water aquifers. The threat posed by abandoned wells cannot be overstated since thousands of them are thought to exist in the County at unknown locations.

Activities which threaten groundwater quality include fuel storage, dry cleaning, solvent storage, auto repair, and agriculture. Any activity using synthetic or refined organic chemicals threatens groundwater quality. Most organic chemicals are soluble to some degree in water, some are highly soluble. These chemicals either leach directly to the groundwater aquifer or they dissolve in infiltrating water which then carries them to the aquifer. Agriculture contributes nitrates, fertilizers, pesticides, and fecal material to the aquifers, though the fecal material is usually broken down before it reaches a well. These agricultural contaminants are very water soluble and travel relatively quickly to the aquifers. Rural development also poses threats to groundwater quality and these threats may differ from the prior agrucultural based threats.

Although much is known about the County's groundwater basins and how to protect the groundwater from contamination, questions still exist about the relative sensitivity of many areas. There are areas in the County that have been the subject of various hydrogeological studies and other areas that have received little or no analysis. Also, few of the areas studied have received similar types of analysis. This lack of a uniform and in-depth study of the entirety of each basin leaves the question of the sensitivity of some areas in the basins unanswered.

The goal of this study was to create a numerically-based map depicting the relative sensitivity of the groundwater to surface and near surface contamination for any area in the groundwater basins. The USEPA DRASTIC methodology is particularly well suited for this task. DRASTIC uses generalized subregional data which is relatively easy to obtain. It also assumes that the contaminants move with water, which is a worst case scenario. Major drawbacks to using DRASTIC are its inability to be used at the site level and the number of assumptions required at each step. The sensitivity map thus created is most applicable to water soluble contaminants such as nitrate and Methyl tert-Butyl Ether, though, by the mechanism described earlier, it is usable for most organic chemicals as well. The final map provides new information to aid in groundwater protection efforts.

Sensitivity, as used in this document, refers to how well an aquifer is protected from surface contamination based on its intrinsic, or hydrogeologic characteristics. Vulnerability, which is another common term, takes into account both the sensitivity of an aquifer and the potentially contaminating activities occurring at the land's surface. DRASTIC is concerned solely with aquifer sensitivity.

METHODOLOGY

Overview

The final map in Figure 1, showing the sensitivity of the groundwater to surface contamination, was created by combining the values of seven pertinent hydrogeological parameters. These parameters are (1) Depth to groundwater, (2) amount of Recharge, (3) Aquifer media type,

(4) Soil type, (5) Topography (slope), (6) Influence of the vadose zone, and (7) hydraulic Conductivity. Each of the seven parameters is represented in an individual GIS layer. Rating values are assigned to each subarea in the layers based on recommendations in the DRASTIC guidance document (USEPA, 1987). Then the values in each layer were multiplied by a weighting factor also recommended by the DRASTIC guidance document, see Table 1. To create the final map, a GIS was used to combine the various weighted values of these polygon (area) layers for all points in the groundwater basins. The creation of each of the seven initial layers will be described individually in the following sections.

Depth to Water layer

Rationale

The depth to water is important because it determines the distance a contaminant must travel to reach groundwater. This distance indicates the amount of contaminant attenuation possible prior to it reaching the aquifer. The dtw layer, shown in Figure 2, was created from the depth to first water records for leaking underground storage tank (UST) cases as reported to the District's Leaking Underground Storage Tank Oversight Program (LUSTOP). This data is stored in LUSTOP's Felix database. This data was used for both the confined and unconfined aquifer zones. The depth to first water is the suggested data for use in the unconfined zones. However, for the confined zones, the DRASTIC manual suggests using the top of the aquifer as the dtw. We decided to use the depth to first water for confined aquifer areas as well because the prevalence of abandoned wells in the confined zones may effectively connect the shallow first water to the deeper drinking water.

Method

Leaking UST site location and dtw data was downloaded from the Felix database in May 1999. Initially, all of the sites with dtw information were plotted in the GIS as points. Then, for clusters of sites where the sites were closer than about 500 feet, the site with the smallest dtw was chosen and the other sites were deleted so they would not be included in the analysis. This filtering of the data was required because there are frequently large, greater than 50 feet, differences in the dtw between neighboring fuel leak sites. When dtw contours are generated with unfiltered data, the resulting contours have many unrealistically steep gradients. For the readers information, the differences in dtw between adjacent sites are due to water depths being measured at different times, the construction of the wells being different, or the geologic differences between the sites.

Contours, or more precisely depth ranges, were then generated using Arc/Info's TIN and GRID modeling programs. TIN was first used to create a network of lines and surfaces connecting each point to its nearest neighbors. A grid was then created, using GRID, from the tin layer. This grid had a grid spacing of 100 feet to provide adequate smoothness of the final layer for typical uses of the map. This method of going from points to tin to grid reduces the number of anomalous contours created by GRID in areas with sparse data. Then GRID was used with the range option to create polygons representing the ranges of depths specified in the DRASTIC manual, see Table 1. This range layer was then screened and edited by hand to eliminate any anomalous polygons which were created. Finally, the DRASTIC ratings and weights were applied to each depth range based on the values in Table 1.

Recharge of Groundwater Layer

Rationale

Recharge, actually net recharge, is the total amount of water that reaches the aquifer. It equals rainfall less runoff, evapotranspiration, and waters retained by the soil. The amount of groundwater recharge is important because it is recharge from precipitation that is the dominant vehicle carrying the contamination from the land surface to the aquifer. The groundwater recharge layer, shown in Figure 3, was created by combining the average rainfall for Santa Clara County with a land use map for the County from the Association of Bay Area Governments (ABAG). The rainfall map was originally developed by Mr. Abdullah Saah, of the District, and was digitized for this project. The ABAG map shows land use and land cover down to the parcel level and was augmented with storm water retention values that were based on the land use or cover. We did not take into account evaporation, transpiration, or soil wetting in this study. This minor deviation from the suggested guidance was made because rainfall here is concentrated in the four months of December, January, February, and March and there is little evapotranspiration during this cold time of year. Also, evapotranspiration does not vary greatly (+/- ½ inch, Pruitt et.al. 1984) across the valley and, therefore, trying to pinpoint an exact value for every point in the basins would be very time consuming without a concomitant improvement in map accuracy.

Method

The average rainfall map was first digitized using Arc/Info and our digitizing board. Each contour line was digitized using sufficient nodes to accurately represent its general shape. A polygon layer was generated from the lines and then labels of rainfall range, in inches, were added as a descriptive attribute. For land use and cover, a digital copy of ABAG's map for Santa Clara County was obtained from ABAG. This map contains the County's land use codes for each parcel. Rainfall retention attributes were then added to each polygon. The value added was determined by the land use code that can be used to estimate the percentage of land covered with impermeable material. The rainfall retention factors range from 0.2 (20 percent) to 0.8 (80 percent) (Rau and Wooten, 1980). Finally, the rainfall and land use layers were combined using Arc/Info and the appropriate ratings and weights were added from Table 1, to create the polygons shown in Figure 3.

Aquifer Media

Rationale

Aquifer media is the type of rock that makes up an aquifer, that unit of the subsurface that can yield usable quantities of water. The aquifer media type is important because it provides an indication of the path length a contaminant must travel once it reaches an aquifer. This in turn signifies the contact time a contaminant has with the media prior to reaching a well and, therefore, the attenuation potential. All of the significant aquifers in the Santa Clara County groundwater basins are of the sand and gravel type. These individual aquifers differ in the size distribution of their media and how well washed they are of fine-grained clay and silt. The hydrographic unit GIS layer, described in the Hydrographic Unit Delineation Report (Parton, 1996), provides outlines of these distinct aquifer units and descriptions of the geologic material in the aquifers in each unit. The aquifer media layer shown in Figure 4 was created by combining the general aquifer type with information on individual hydrographic units.

Method

The DRASTIC rating for sand and gravel aquifers provides a range of rating values to use based on how clean an aquifer is and its predominant particle sizes. This range is from four to nine. To determine the value to use for a particular subarea, the Hydrographic Unit Delineation Report was consulted. Values from its Table 1 were assigned to each polygon subregion in the hydrographic unit GIS layer, based on the description of that subregion in the report. Lines between regions assigned the same values were dissolved, leaving larger polygons. These polygons now represent the different aquifer subregions, forming the aquifer media layer.

Soil Media

Rationale

Soil media refers to that portion of the earth that is generally within six feet of the surface. Soil significantly effects the rate and amount of recharge and the rate of contaminant movement from the surface to groundwater. Some soils have high organic content causing some contaminants to adsorb to the soil, thus limiting the contaminant's movement and allowing more biochemical degradation of pollutants. Other soils may be rich in clays, which again limit contaminant movement. Still others may have little organic or fine-grained materials, allowing rapid movement of contaminants to the aquifer. The soil media layer in Figure 5 is derived from a Soil Conservation Service map.

Method

A digitized copy of the soil map developed by the United States Soil Conservation Service was obtained from District files. The soil classifications were analyzed and rating values from Table 1 were assigned to each area based on best professional judgment. The boundaries between areas with the same ratings were dissolved, leaving the final layer.

Topography

Rationale

Topography refers to the slope of the land surface. Topography is important in determining pollutant infiltration potential because it greatly influences whether or not water or a pollutant will run off or sit on a particular spot long enough to infiltrate the ground. The topography layer in Figure 6 is the result of processing United States Geological Survey (USGS) Digital Elevation Models (DEM). These are 30-meter DEMs which means that the points defining elevations are 30 meters, or about 100 feet, apart. This level of accuracy, aside from it being the most accurate available at the time, is appropriate for this type of study since this study will not provide site level information.

Method

DEMs from the USGS were used to create the topographic layer. Separate DEMs were obtained from the USGS web site, each having elevation points 30 meters apart. They were joined to create one large DEM for the County. Arc/Info was then used to create the slope layer. Lastly, ratings for each percentage of slope were added as an attribute based on values in Table 1.

Influence of the Vadose Zone

Rationale

The vadose zone is the unsaturated material between the ground surface and the aquifer. It generally includes the soil zone. Nevertheless, the soil has effects distinct from the rest of the vadose zone and so was considered separately. The type of vadose media determines its contaminant attenuation characteristics. Biodegradation, filtration, chemical reactions, volatilization, and dispersion are processes that may occur in the vadose zone. Santa Clara Valley groundwater basins consist of principally two types of vadose materials, those that inhibit vertical water movement and those that allow relatively free movement of water from the surface. The confined areas are dominated by clay aquitards that effectively prevent significant vertical water movement. The area of relatively free water movement, the forebay, is considered unconfined and is represented by interbeded layers of gravels, sands, silts, and clays. The silt and clay layers in the forebay are generally discontinuous and do not provide important confining properties to the aquifer. Since the forebay areas vary greatly from one point to another, bore hole information was used to define and subdivide these areas. The vadose layer is shown in Figure 7.

Method

The confined zones are reasonably well defined and, accordingly, these boundaries were used in the DRASTIC analysis. All that was required for the confined zones was the assignment of the rating factor for confined aquifers. The unconfined zones were first determined by subtracting the confined zones from the entire groundwater basin. Then this area was further subdivided by using geologic information from well logs in these areas. These logs provided details on the thicknesses of high and low permeability materials in the immediate areas of the wells. The features of the predominant or controlling vadose material were added to the well attribute table of the Allwells well GIS coverage. The controlling material would be clay if there was a significant, generally greater than 10 feet thick, clay deposit that would restrict water movement. If little clay or silt were present, meaning no 10 feet thick or thicker silt or clay zones, then the area would be defined as having a relatively porous vadose material. Theissen polygons were created around each well in the unconfined zones and assigned values based on the controlling geologic parameter. Then Arc/Info was used to dissolve the boundaries between adjacent polygons with the same values as assigned to the areas based on Table 1. Finally, the confined and unconfined zones were joined to create one vadose layer.

Hydraulic Conductivity

Rationale

Hydraulic conductivity is a measure of the ability of a geologic formation to transmit water. It is important in this study because the rate at which water flows controls the rate at which contaminants also flow. The hydraulic conductivity layer is shown in Figure 8.

Method

The hydraulic conductivity for the North County aquifers was determined by CH2MHill in1992 as a part of their development of the District's groundwater model (CH2MHill, 1992). The conductivities of the South County aquifers were determined by associating them with similar aquifers in the North County. By using the hydrographic units information (Parton, 1996) and consulting with District geologist Mr. Tom Iwamura, areas in the South County were defined. Then similarities between areas in the North and South County were identified. Areas in the south were then assigned the conductivities of the corresponding areas in the north. Lastly, values from Table 1 were assigned to each conductivity zone.

RESULTS

The final DRASTIC map is shown in Figure 1. Several areas in the County of known sensitivity were compared with the sensitivity portrayed in the final map and in each case the map agreed with what is known about the groundwater sensitivity in that area. The Great Oaks/Santa Teresa area is known to be highly sensitive and the map shows them as such. The western forebay of Los Altos, Mountain View, and Cupertino are known to have low sensitivity due to deep groundwater and the map agrees with this knowledge. The map also confirms that the areas in the County with large toxic contamination problems also have highly sensitive groundwater while low sensitivity areas do not have large scale contamination.

Areas in the northern confined zone along Coyote Creek, where saltwater intrusion has occurred, see Figure 9, were compared to the sensitivity map. These areas are assumed at first glance to have low sensitivity due to the confining layer. But when the presence of thousands of unknown abandoned wells is factored in, this northern area then has many highly sensitive areas, since the saltwater contamination is due to abandoned wells. That these areas, which are intruded with saltwater, actually are highly sensitive reinforces the decision to use the depth to first water in these confined zones.

DISCUSSION

This map has a higher resolution than the strict DRASTIC methodology maps due to the use of GIS and high resolution base data. The map is applicable to areas greater than 50 acres. Of all the factors used to create the final map, the vadose zone and the dtw have the greatest effects on the ratings. This is because they have larger weighting multipliers than the other factors. The vadose zone layer was created from well accepted geologic data with little subjectivity involved. The dtw layer in the confined zone uses the depth to first water and not the depth to the bottom of the aquitard. This was done to account for both the presence of unknown abandoned wells and for wells with multiple screens that may interconnect aquifers. Another approach could have been to use the District's abandoned well GIS layer and draw buffers around the wells with no or unsatisfactory sealing. Then only these buffered areas would use the depth to first water and the other areas in the confined zone would use the depth to the bottom of the aquitard. Because there are an unknown number of abandoned wells in unidentified locations, the safest approach is to assume these wells are ubiquitous and raise the sensitivity of the entire area.

Limitations to the map include accuracy at its periphery, at internal boundaries, and the usable resolution. At the edges, from the edge to about 1000 feet into the map, the map may not have sufficient justification for the designated sensitivity. This is due to the probability that the base data was extrapolated from a point up to 1000 feet from the edge. Regarding adjacent areas with different sensitivities, sites in areas with lower sensitivity near the border of high sensitivity areas should be considered to be in the higher sensitivity area and given heightened scrutiny. The practice of using the higher sensitivity near borders is needed because the 50-acre resolution limit of the map creates an inherent inexactness in the locations of the boundaries between different zones.

The DRASTIC map cannot be used to replace site-specific investigations. This is due to the regional character of the base data from which the map is derived. It does highlight areas that are sensitive, but even areas with lower indicated sensitivity should be investigated on a site basis to verify their suitability to particular potentially contaminating activities (PCA).

CONCLUSIONS AND RECOMMENDATIONS

Pollution prevention is a prerequisite to the availability of sufficient quantities of potable water. The groundwater sensitivity map created by this work provides essential information on groundwater protection needs to District staff, water retailers, and to city and county planners. The map accurately contrasts the more and less sensitive areas in the County and should be used during the review of development plans. By comparing the current knowledge of the basins to information in the map, the map also highlights areas in the County where further groundwater study may be needed. Finally, since the map shows sensitive areas, it will be instrumental in the development of source water protection areas.

This map should be presented to city and county planning departments to educate their members on the sensitivity of groundwater in the hope that they will direct new PCAs to less sensitive areas. These presentations should include the locations of wells, hazardous material storage tanks, major roads, and other potential contaminant sources to show how vulnerable the groundwater is. Also, undeveloped areas, such as north Coyote Valley, could be overlaid on the map to identify zones that should have restricted types of development.

The finalized groundwater sensitivity map based on the DRASTIC methodology is available for use with GIS. It is located on the District's GIS server under groundwater protection.

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TABLE 1

DRASTIC RATINGS AND WEIGHTS

1. Depth to Water (ft.)

Range	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
71-100	2
>100	1

2. Recharge (in)

Range	Rating
0-2	1
2-4	3
4-7	6
7-10	8
>10	9

3. Aquifer Media

Type	Rating
Sand & Gravel	4-9

4. Soil Media

Type	Rating
Gravel	10
Sand	9
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Massive Clay	1

5. Topography (%)

Range	Rating
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

6. Vadose Zone Media

Type	Rating
Silt/Clay	2-6
Sand & Gravel with fines	4-8
Clean Sand & Gravel	6-9

7. Hydraulic Conductivity(gpd/sqft)

Range	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
>2000	10

DRASTIC Weightings

Rating x Weight =

1. ____ x 5 = ____
2. ____ x 4 = ____
3. ____ x 3 = ____
4. ____ x 2 = ____
5. ____ x 1 = ____
6. ____ x 5 = ____
7. ____ x 3 = ____

Figure 1
Santa Clara Co. Groundwater Sensitivity

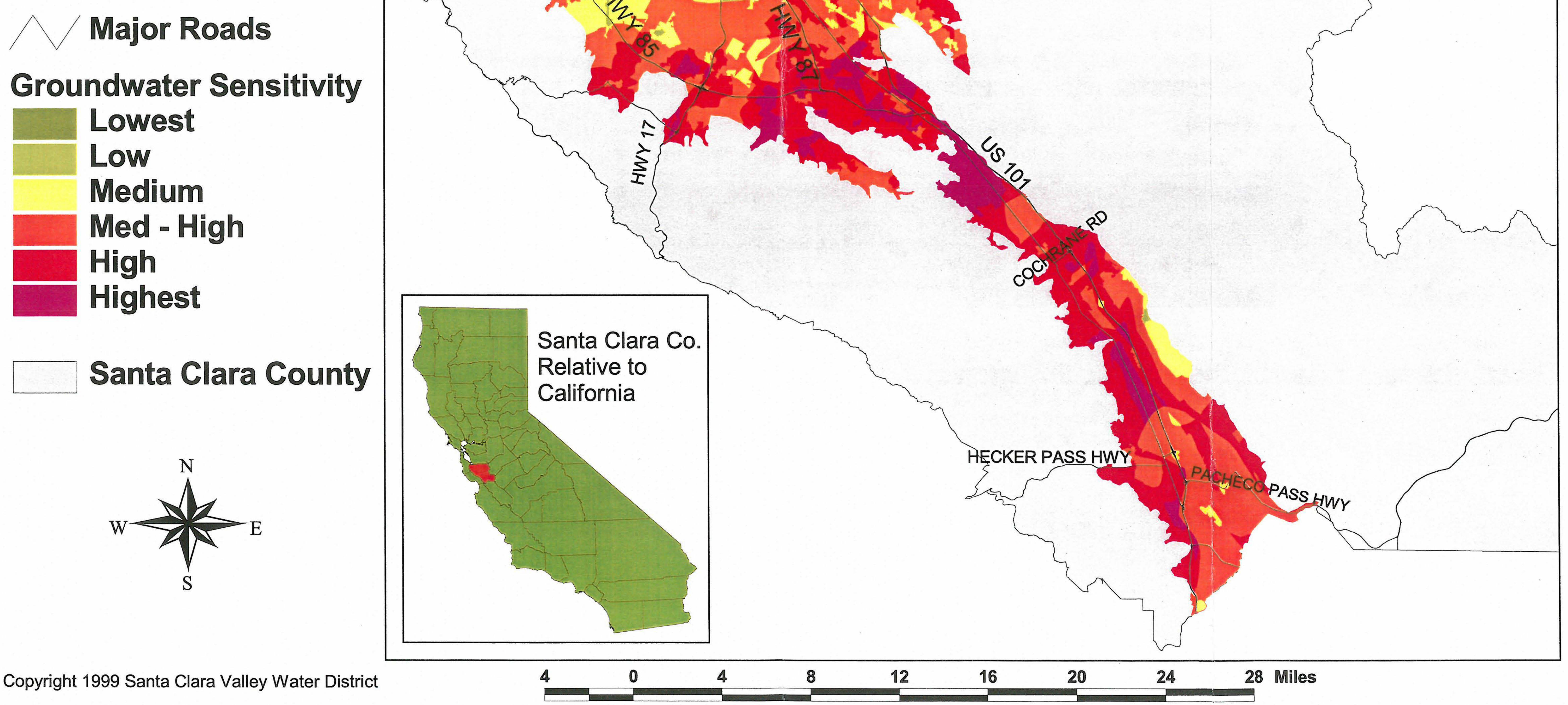

Figure 2
Depth to Water

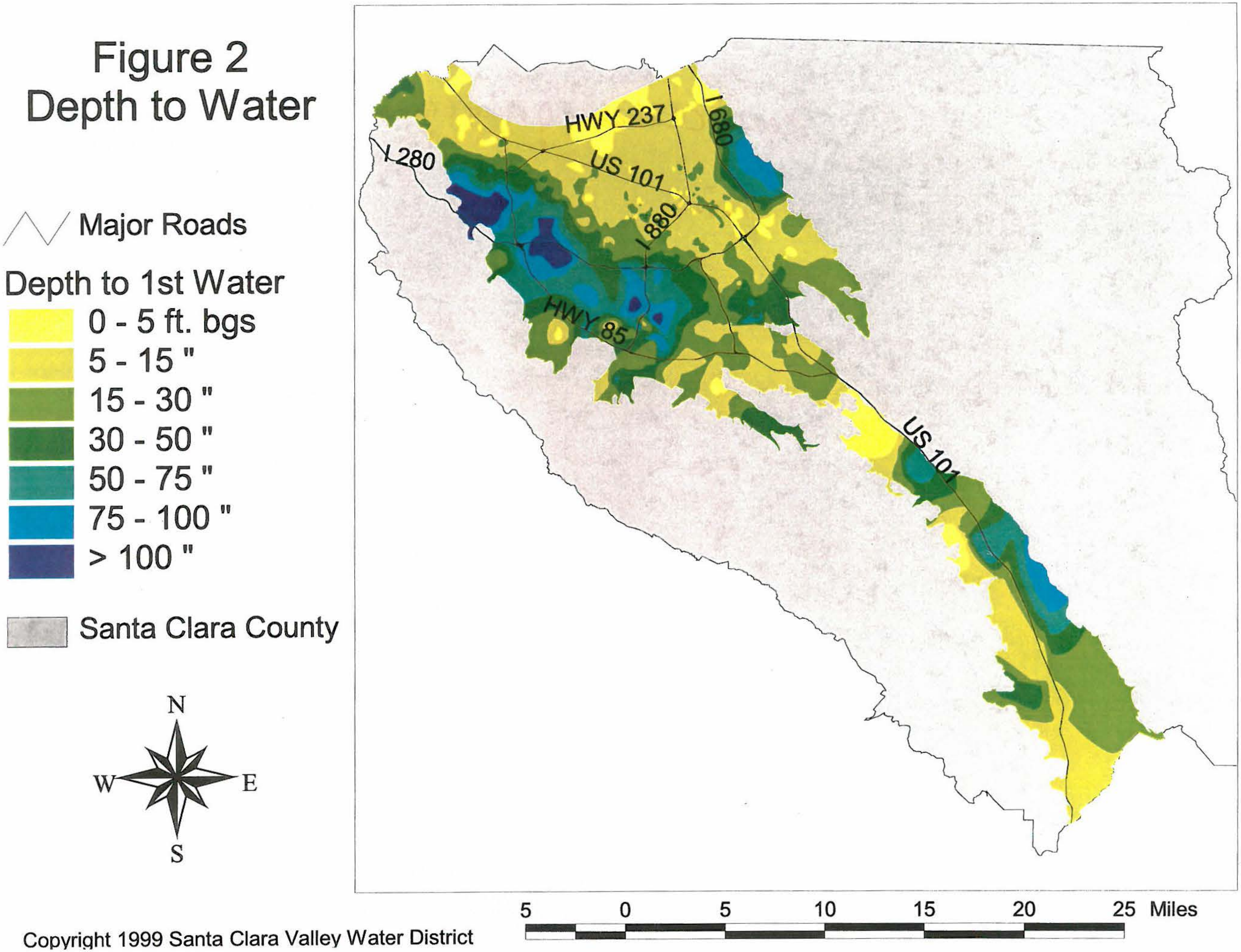

Figure 3
Recharge

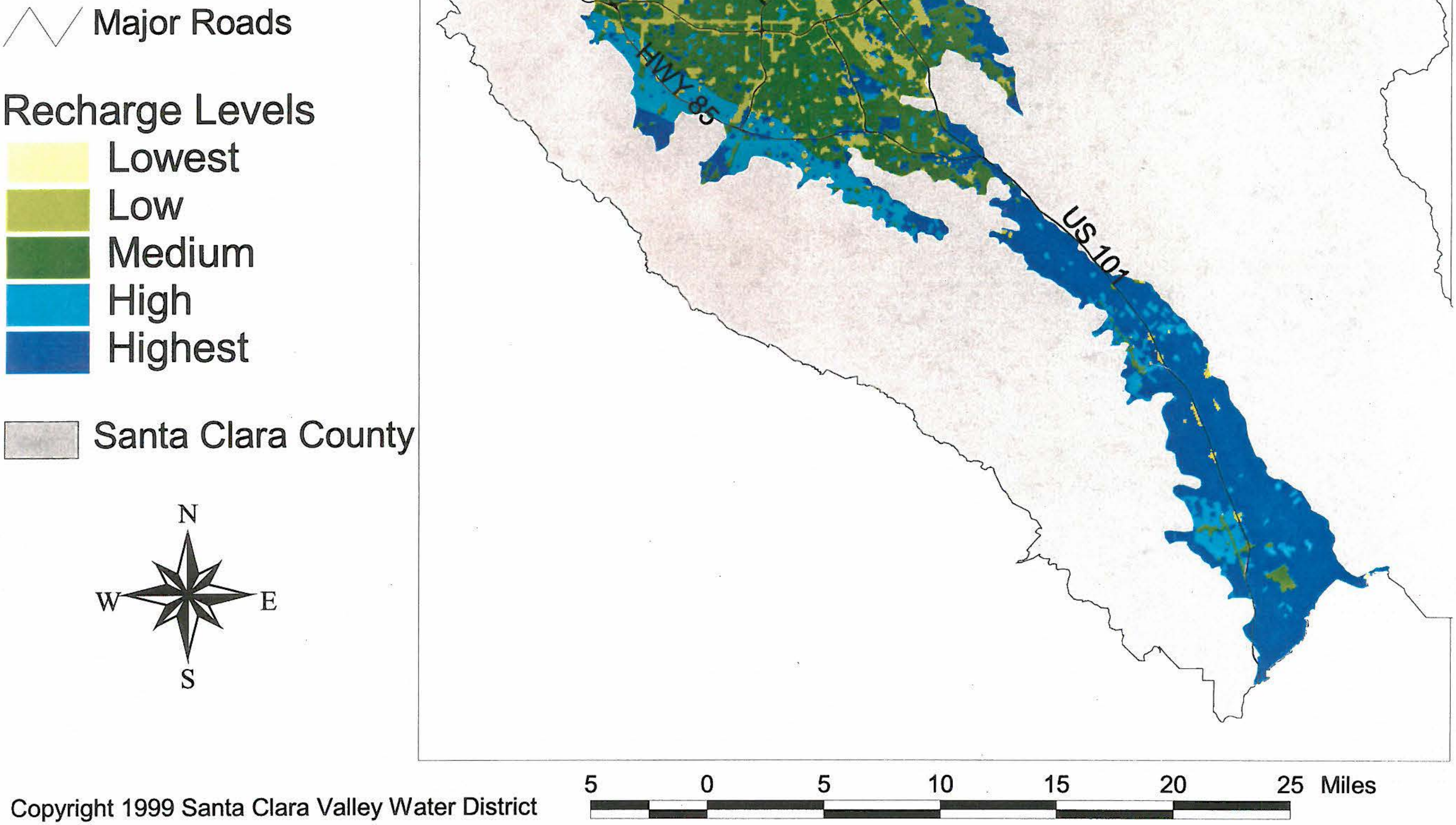

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Figure 4
Aquifer Influence

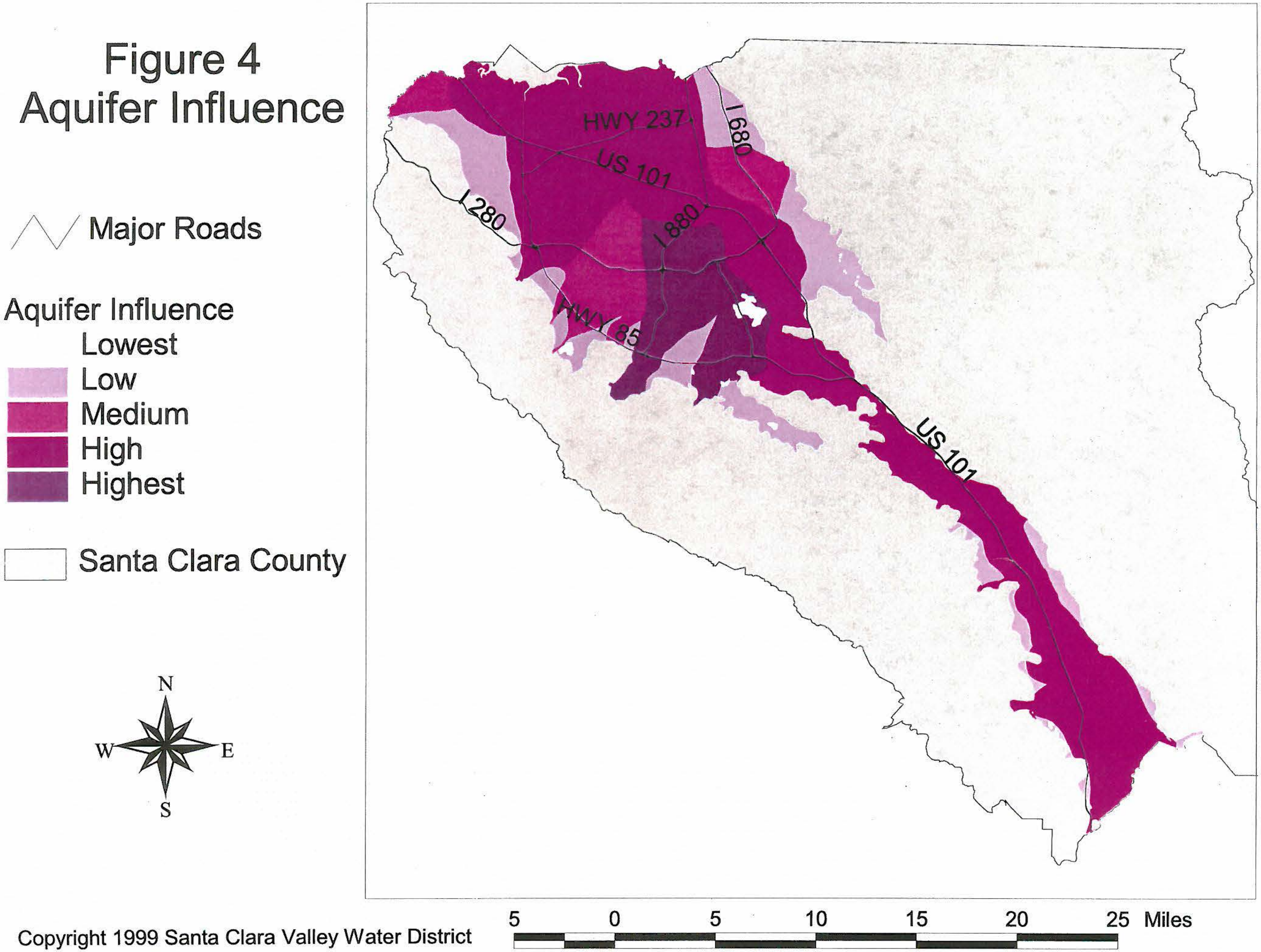


Figure 5
Soil Influence

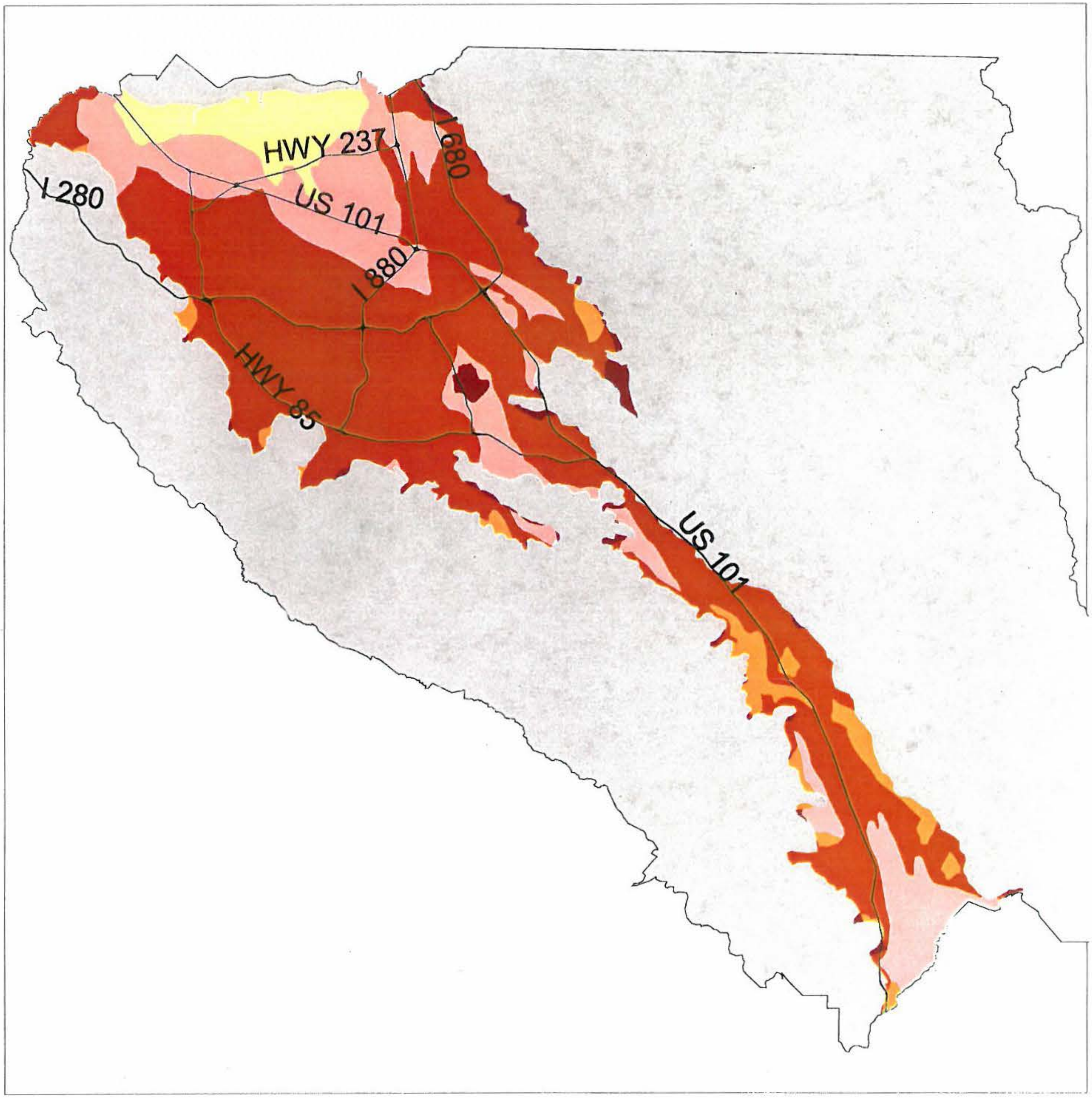


Figure 6
Topography Influence

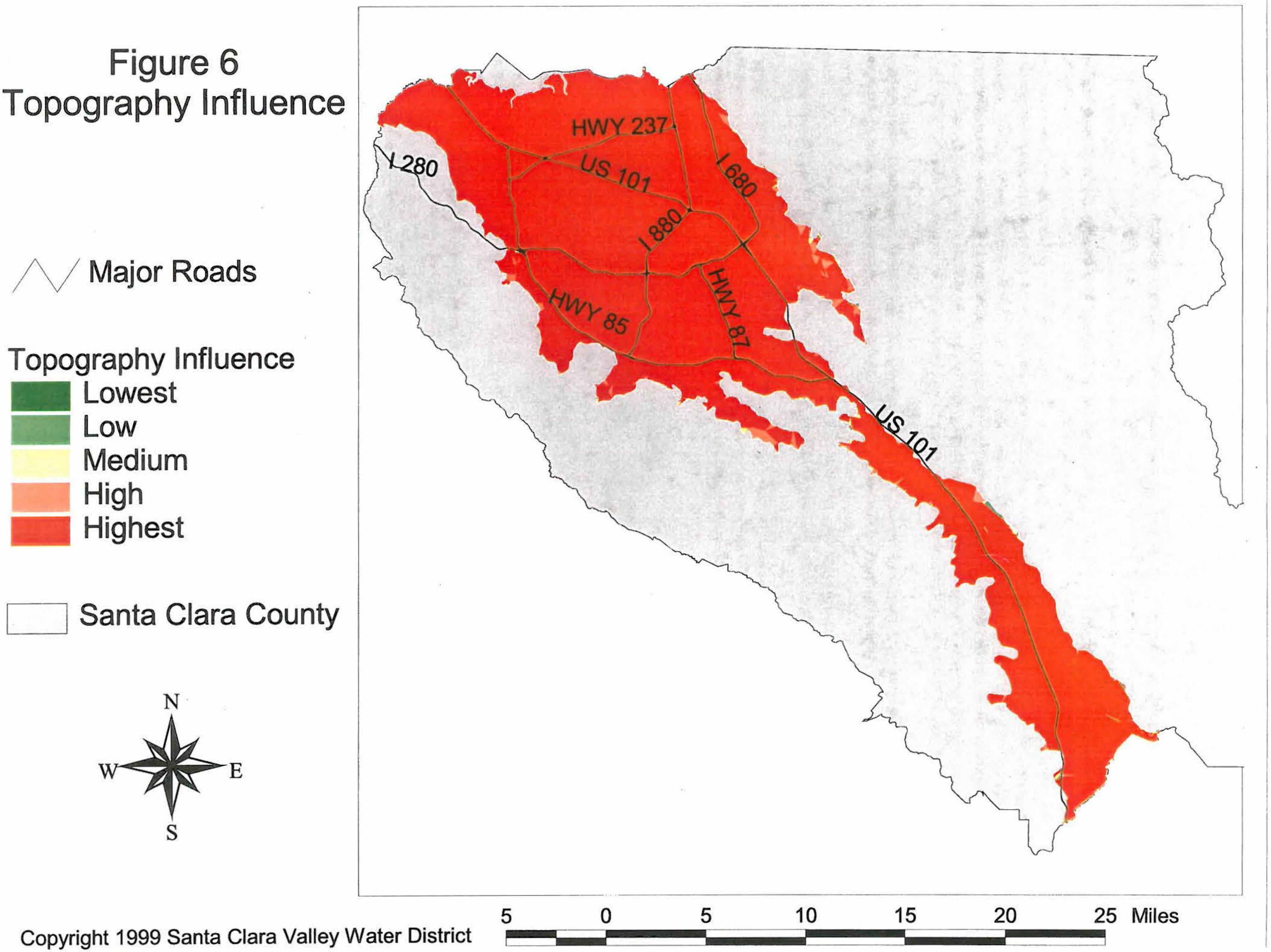


Figure 7
Aquifer Protection by Vadose Zone

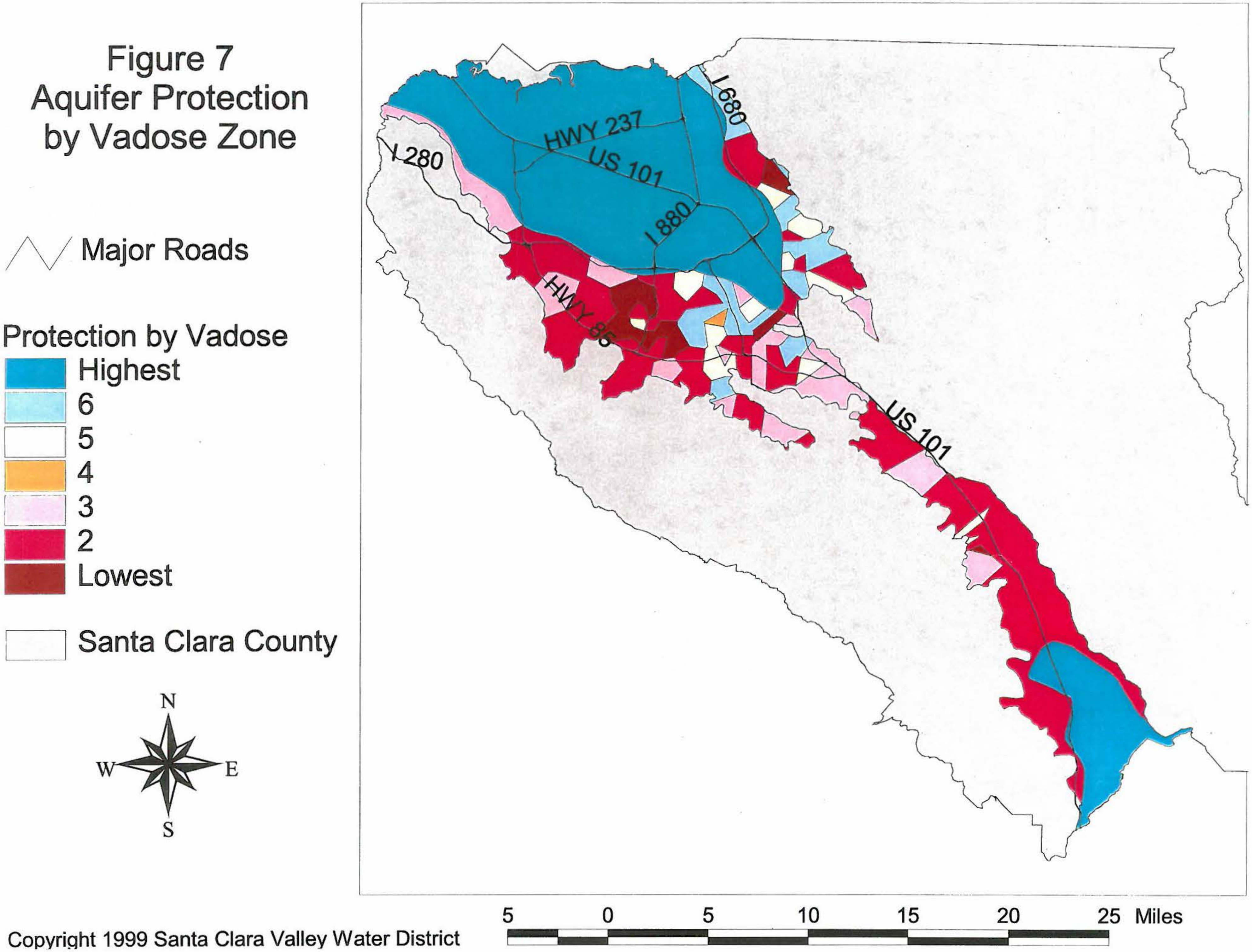


Figure 8
Hydraulic Conductivity

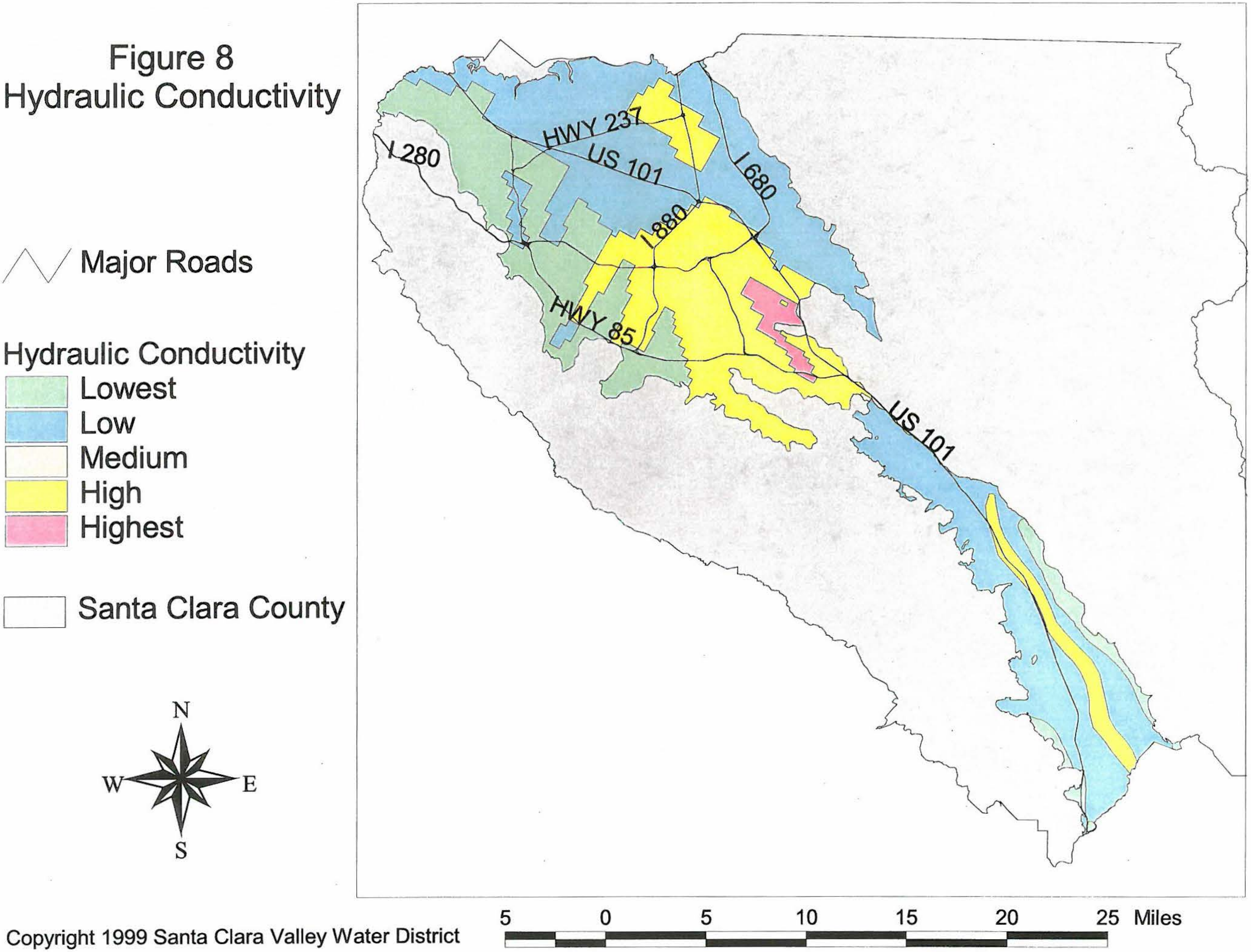
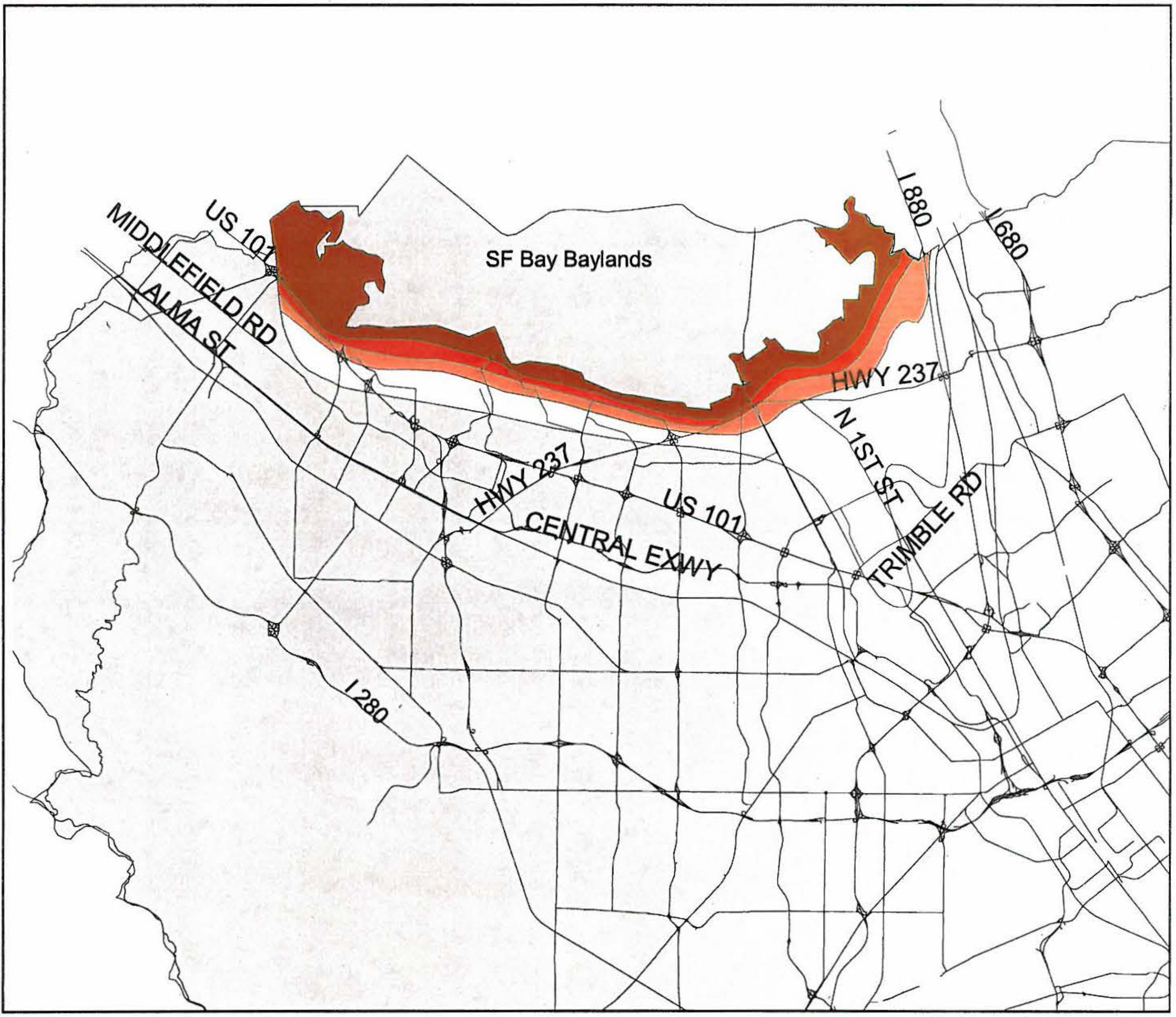


Figure 9 Saltwater Intrusion



From: Salt Water Intrusion Monitoring Report, Santa Clara County, Randy Behrens, October 1999.